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COVER SHEET FOR TECHNICAL MEMORANDUM

TITLE – A Preliminary Estimate of Maximum Earth Orbital Mission Durations for a CSM/Auxiliary Module/S-IVB Workshop Configuration

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Augmented CSM Mission Capabilities

ABSTRACT

This memorandum provides a preliminary estimate of maximum mission durations achievable with a CSM/Auxiliary Module/S-IVB Workshop launched by an S-IB. Average mission requirements for electrical power are treated parametrically with a range from 2 to 4 kw. The CSM is considered to be essentially an unmodified Block II configuration with the exception of the EPS and provisions for utilizing consumables stored in the Auxiliary Module. Graphs are presented from which mission durations can be estimated as a function of experiment payload and average electrical power requirements. The assumption of a minimally modified CSM provides a preliminary benchmark against which the effects of more extensive modifications can be measured.

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SUBJECT: A Preliminary Estimate of Maximum Earth-Orbital Mission Durations for a CSM/Auxiliary Module/S-IVB-Workshop Configuration - Case 218

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FROM: D. J. Belz

TECHNICAL MEMORANDUM

INTRODUCTION

Recent Saturn Apollo Applications planning has been directed toward the achievement of Earth-orbital missions of one-year duration to provide a technological base for eventual manned planetary exploration. This memorandum provides a preliminary estimate of maximum mission durations achievable with a single-launch CSM/Auxiliary Module/S-IVB Workshop configuration placed in Earth orbit by an SIB.*

Constraints on orbit parameters, CSM modifications, and Auxiliary Module (AM) definition assumed in this study are as follows:

1. SIB payload capability is based on a circular orbit of 200 NM mile altitude achieved with a launch azimuth of 90° (∿28.5° orbital inclination).

2. Mission durations are in excess of 30 days, i.e. greater than the nominal capability of the CSM/SSESM/S-IVB Workshop configuration.

3. CSM configuration is Block II with the exception of fuel cells in the EPS. Block II subsystems qualified for 14 days are assumed, for purposes of this study only, to be capable of extended lifetimes without modifications other than the provision of additional expendables.

4. Expendables for CSM operation beyond 14 days are stored in the Auxiliary Module (AM).

5. The crew for each mission consists of three men.

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*The Auxiliary Module (AM) concept is functionally similar to the Spent Stage Experiment Support Module (SSESM); the term "AM" is employed here to distinguish between the particular configuration (SSESM) currently being designed for Flight 209 and other possible configurations capable of extended mission durations and more extensive subsystems support to experiments.

6. Electrical power requirements are considered parametrically with variations from approximate housekeeping loads to the maximum obtainable within the constraints of EPS radiators on the Block II SM.

Estimates of maximum mission durations given below are based on a comparison of required S/C weights-in-orbit with the payload capability of an SIB launch vehicle.

I. SPACECRAFT CONFIGURATION

The overall spacecraft is considered for convenience to be composed of three modular components: CSM, Auxiliary Module (AM), and S-IVB Workshop. The S-IVB Workshop is basically an S-IVB spent stage with an O_2 atmosphere in its hydrogen tank; environmental control is provided by the Auxiliary Module (AM) while electrical power is obtained from the CSM EPS. The Auxiliary Module is mounted within the SLA section of the launch vehicle on the LEM attach points; major components of this module are an airlock tunnel to provide access from the CM to the S-IVB Workshop and S/C exterior; an ECS to provide a shirt sleeve environment in the airlock tunnel and in the Workshop; expendables and associated storage facilities to support the entire S/C beyond 14 days of operation; and instrumentation to monitor its own systems plus the S-IVB stage passivation system which is required to render S-IVB pressure vessels and armament safe prior to manned entry of the Workshop. The CSM, as mentioned above, is assumed to be essentially a Block II configuration with one major exception: the Pratt & Whitney (P&W) fuel cells of the Block II EPS are replaced by asbestos membrane fuel cells of the type currently under development by Allis-Chalmers.

II. ESTIMATES OF SUBSYSTEM WEIGHTS

Nonexpendable Items

Electrical Power System:

The P&W Bacon-type fuel cells employed in the Block II CSM EPS have a relatively deterministic time and temperature dependent failure mode. NASA/MSC has estimated that these cells can be qualified for missions of approximately 30 days duration by derating their power output, thus reducing operating temperatures and retarding cell degradation (Reference 1). For mission durations appreciably greater than 30 days and electrical power requirements significantly greater than S/C housekeeping loads extensive development work on the P&W cell would be required to increase operating lifetimes at normal power output and/or to provide a capability for inflight starts. An alternative to extending development of the P&W cell beyond ∿30 days operating lifetime is to consider flight qualification of an asbestos membrane fuel cell for durations between 1,000 and 1,500 hours (∿40 to 60 day missions); Allis-Chalmers is currently under contract to NASA/MSC to develop a 1,500 hour fuel cell module. It is estimated in Reference 1 that such a module would weigh approximately 170 lbs. for a rated power output of ∿2 KW.

Lack of precise information on failure modes as well as other problems may prevent early flight qualification of such a module; for purposes of this study, however, the availability of a qualified, 2 KW, 170# fuel cell module capable of 1,000 to 1,500 hours of operation is assumed. Table 1 indicates total fuel cell weights for mission durations from 30 to 75 days at average EPS outputs up to 4 KW; it is assumed that one spare module is carried regardless of average power level or mission duration.

In calculating CSM weights below, a credit of 660 lbs. is taken for three P&W modules removed from the SM; appropriate total fuel cell weights from Table 1 are then included, in accordance with the previously mentioned assumption that all fuel cells for the entire S/C will be carried in the SM. (Inclusion exclusively in the SM simplifies the problem of heat rejection by permitting use of the unmodified SM EPS radiators for outputs up to ∿4 KW.*

AM Environmental Control System:

To minimize the complexity of the CSM/AM interface it is assumed that environmental control of the AM together with the S-IVB Workshop will be provided by an environmental control system located in the AM.** The estimated weight of the ECS is 450# based upon corresponding Gemini hardware weights (Reference 4). This implies that no more than two crew members occupy the Auxiliary Module or Workshop at any given time.

Thermal control of the AM Airlock is maintained by passive means and by varying the temperature and humidity of the S/C atmosphere in the ECS. If the airlock is covered with high-performance super insulation the interior temperature can be held close to the temperature of the pressuring gaseous oxygen (Reference 5). In the absence of an atmosphere in the S-IVB spent stage H_2 tank, the internal surface can be maintained at an average temperature of 30°F by rolling the entire S/C at ∿0.10 rpm. This assumes

*Limitations on power output imposed by SM EPS radiators are discussed in References 2 and 3.

**North American Aviation is currently under contract with NASA/MSC to study the feasibility of using the Block II ECS to support a CSM/SSESM/S-IVB Workshop configuration.

TABLE I - TOTAL EPS FUEL CELL WEIGHTS FOR CSM/AM/S-IVB WORKSHOP MISSIONS FROM 30 TO 75 DAYS DURATION

MISSION DURATION (DAYS)	FUEL CELL OPERATING LIFETIME (HOURS/MODULE)	TOTAL FUEL CELL WEIGHTS	
		EPS OUTPUT UP TO 2 KW	EPS OUTPUT 2 TO 4 KW
30 TO 40	1000	340.	510.
40 TO 75	1000	510.	850.
30 TO 60	1500	340.	510.
60 TO 75	1500	510.	850.

ASSUMPTIONS:

- WEIGHT/MODULE = 170 LBS.
- POWER OUTPUT/MODULE = 2 KW
- IN FLIGHT START CAPABILITY

that the S-IVB tank exterior is painted black, the LOX tank is at near vacuum condition, and that an aluminized mylar curtain closes the opening between the SLA and the Auxiliary Module docking fixture (Reference 5). The mylar curtain serves to protect the Auxiliary Module exposed surfaces from SM RCS plume impingement effects during docking and maneuvering as well as to reduce temperature fluctuations of the S-IVB hydrogen tank's forward dome.

AM Structure:

Principal structural components of the Auxiliary Module are an airlock/tunnel and a support structure to transfer AM reaction loads to the LEM attach points in the SLA. An airlock/tunnel weight has been estimated in Reference 5 to be 911.# Corresponding support structural weights amounted to ∿14% of the total weight suspended from the LEM attach points; support structural weights are estimated herein as 15% of the total Auxiliary Module weight. This percentage is applied below in computing total AM weight requirements for missions of durations up to 75 days.

Instrumentation:

Instruments to monitor and control the cryogenic storage system, Auxiliary Module ECS, and the S-IVB spent stage passivation systems are carried on the AM. An arbitrarily selected allowance of 200.# has been made for this instrumentation in determining total auxiliary module weights.

Consumables

Consumable items required by the CSM/AM/S-IVB Workshop include potable water; hydrogen and oxygen reactants for fuel cells; metabolic oxygen including an allowance for leakage from habitable volumes; food; medical and personal hygiene equipment; and LIOH for removing CO_2 from cabin atmospheres. Rates of consumption for each of these items are assumed, for purposes of this study only, to be as stated in Table 2.

The availability of potable water as a by-product of fuel cell operation is dependent upon the amount of electrical power generated during a given mission and the degree of contamination of water as it leaves the cells. It is estimated that ∿0.77# of H_2O will be produced for each KWH of electrical energy generated. The H_2O requirement for a three man crew (18#/day) can thus be met by an average mission power requirement of slightly less than 1 KW. Minimum, average, and maximum housekeeping loads for the CSM alone are anticipated to be approximately 1.43 KW, 1.57 KW, and 2.58 KW respectively (Reference 3). The EPS can thus be expected to provide water in sufficient quantities to meet crew needs.

TABLE 2 - REQUIREMENTS FOR CONSUMABLES*

ITEM	CONSUMPTION RATE
FUEL CELL REACTANTS	
HYDROGEN	0.0906#/KWH
OXYGEN	0.688#/KWH
POTABLE WATER**	6.#/MAN-DAY
METABOLIC OXYGEN	2.#/MAN-DAY
CM O_2 LEAKAGE	4.8#/DAY
S-IVB WORKSHOP O_2 LEAKAGE (ASSUMED)	10.#/DAY
AIRLOCK REPRESSURIZATION OXYGEN (ONE EVA EVERY THIRD DAY)	1.5#/DAY
S-IVB WORKSHOP INITIAL PRESSURIZATION	287#
FOOD	1.67#/MAN-DAY
MEDICAL & PERSONAL HYGIENE	2.67#/MAN-DAY
LIOH	2.52#/MAN-DAY

*REFERENCES 1, 6-9

**PROVIDED BY EPS

Total mission requirements for fuel cell reactants are dependent on average mission electrical power requirements and mission duration; total mission requirements for metabolic oxygen, food, medical and personal hygiene equipment, and LIOH are dependent on crew size and mission duration. Figure 1 indicates the requirement for non-gaseous consumables, i.e., food, medical and personal hygiene equipment, and LIOH for a three man crew on missions with durations ranging from 30 to 75 days; it is assumed that the CSM carries sufficient quantities of these consumables to adequately meet crew needs during the first 14 days of orbital operations.

Figure 2 indicates spacecraft oxygen requirements for metabolic consumption, electrical power generation, leakage, S-IVB Workshop initial pressurization, and airlock repressurization for an assumed average of one EVA every three days. It is assumed that the Block II CSM cryogenic oxygen storage capability (640# total usable O_2) is retained and used until exhausted; the figure thus presents oxygen requirements in excess of the Block II CSM capability. Tankage (plus residuals) required for the additional O_2 is estimated to require approximately 0.3# of tank for each pound of usable fluid. This estimate is a rough average of the corresponding ratios for Apollo, Apollo X, and AES 45 day E.O.CSM O_2 tanks (References 8 and 9). It should be noted that the maximum flow rate of the present Apollo system is exceeded for the curves associated with 3 KW and 4 KW average electrical power requirements; it is therefore assumed that if such power levels are specified, maximum flow rates can be increased with no appreciable change in system weight. This particular flow rate restriction of course does not apply to the AM storage system which supplements the Block II O_2 tanks.

Figure 3 illustrates spacecraft hydrogen requirements for electrical power generation. As before, it is assumed that the Block II CSM hydrogen storage capability is retained; hydrogen and tankage requirements shown are thus increments above the Block II capability. The ratio of dry tank weight plus residuals to usable H_2 weight is estimated to be 2.5, this estimate having been determined in a manner similar to that described above for oxygen tankage.

Contingency

Total AM weights include an arbitrary weight allowance for miscellaneous equipment items and departures from the nominal system weights described above: This contingency allowance is 5% of the total AM system weight which includes non-expendable and consumable items discussed in Section II.

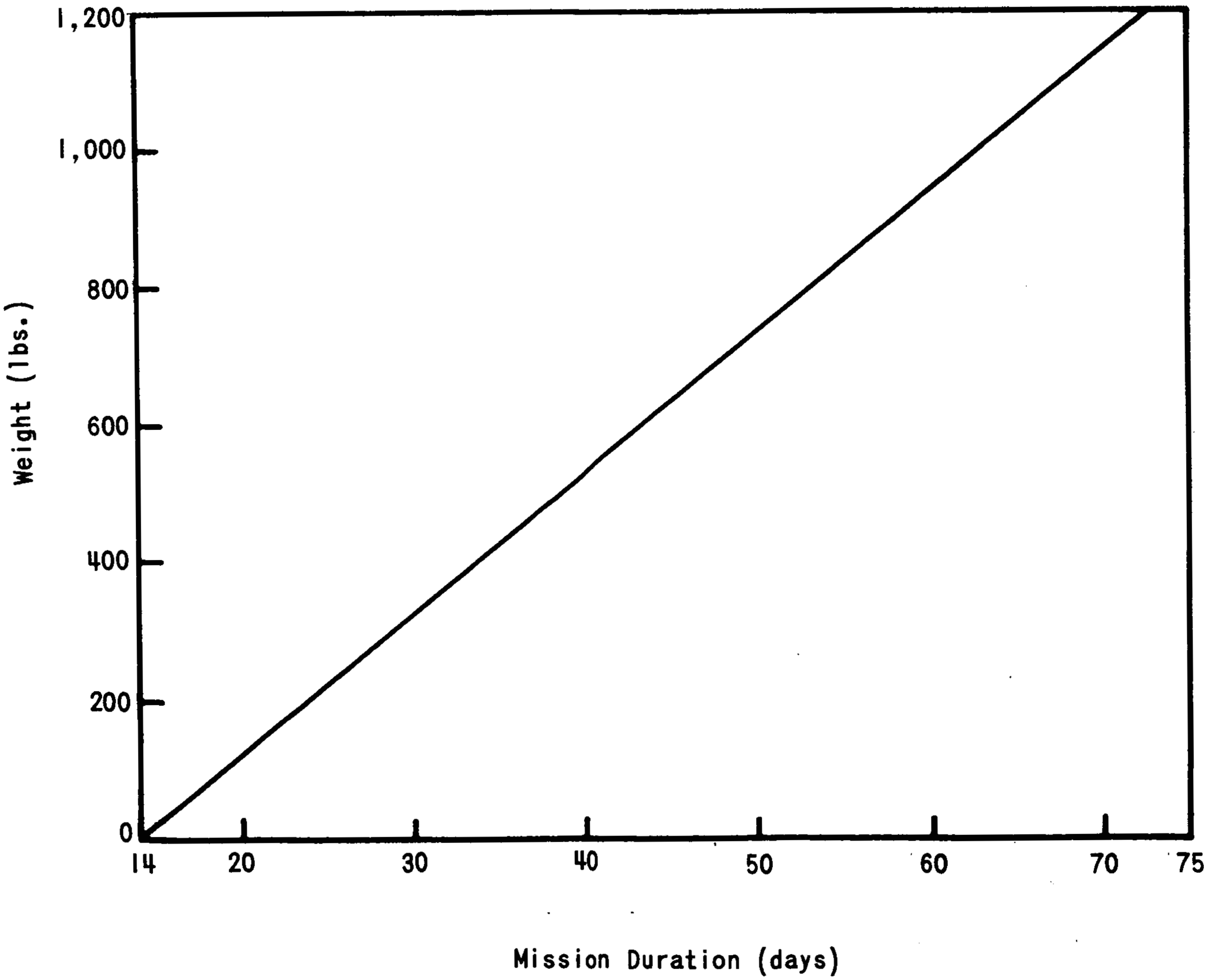

FIGURE 1 - FOOD, MEDICAL & PERSONAL HYGIENE EQUIPMENT, AND LIOH REQUIRED TO SUPPLEMENT THE CSM CAPABILITY FOR MISSIONS UP TO 75 DAYS WITH 3-MAN CREWS

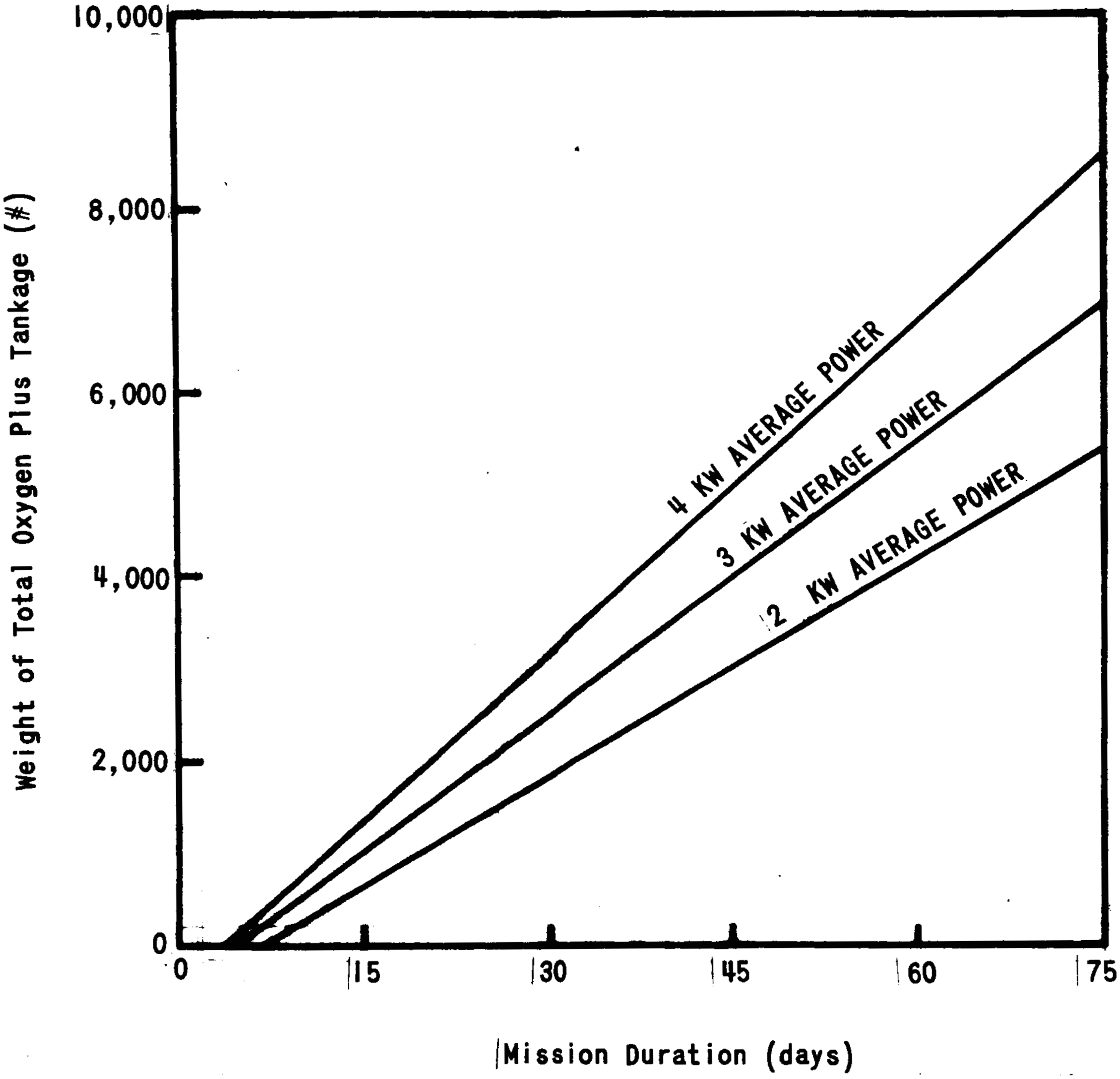

FIGURE 2 - SPACECRAFT OXYGEN REQUIREMENTS IN EXCESS OF BLOCK II CSM CRYOGENIC STORAGE CAPABILITY

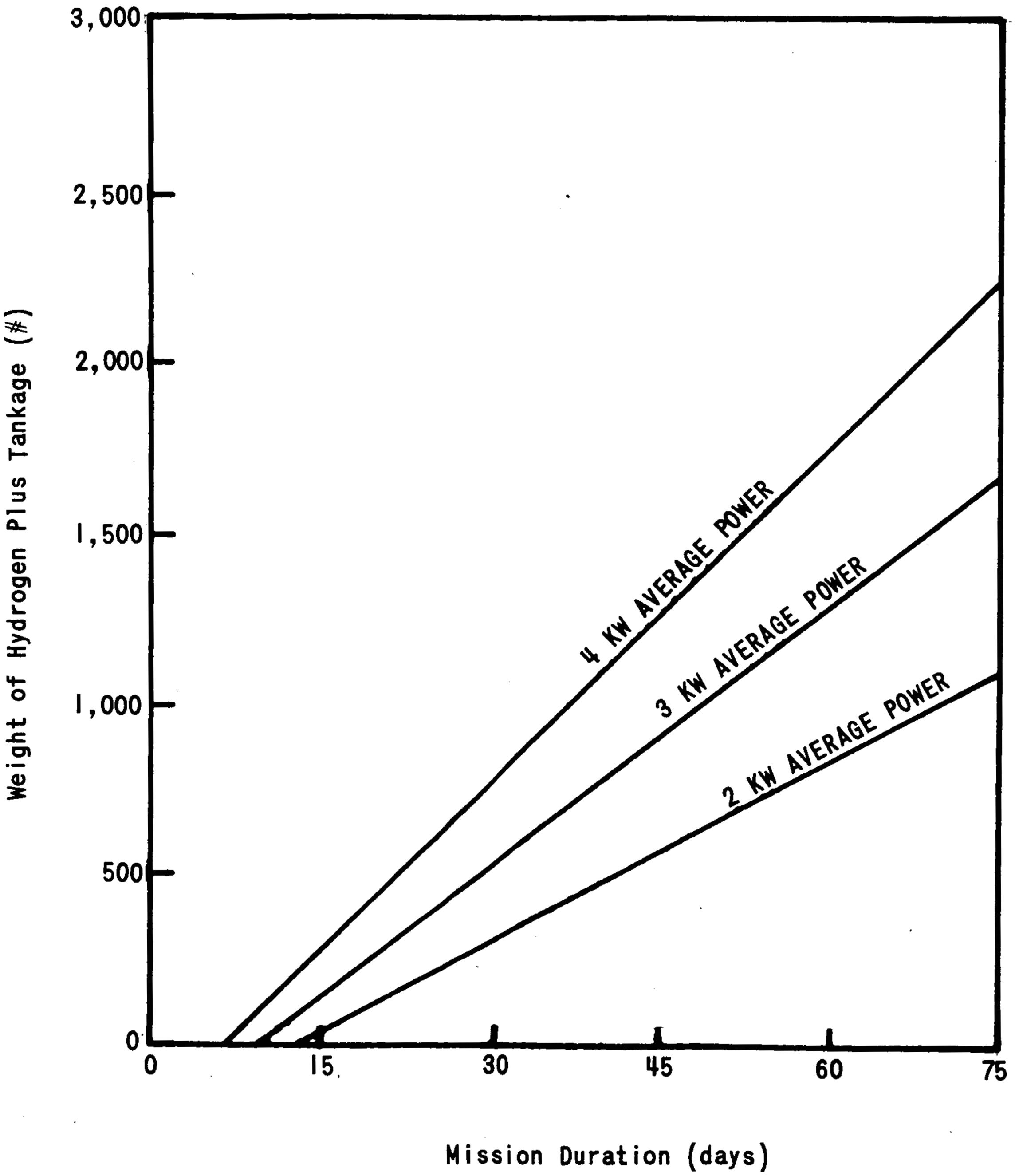

FIGURE 3 - SPACECRAFT HYDROGEN REQUIREMENTS IN EXCESS OF BLOCK II CSM CRYOGENIC STORAGE CAPABILITY

Total Auxiliary Module (AM) Weight Requirements

Total weight requirements for the Auxiliary Module based on the preceding discussion are indicated in Figures 4 and 5 for mission durations from 30 to 75 days and average electrical power requirements from 2 KW to 4 KW. Allowable weights, determined by launch vehicle payload capability and orbital parameters of a reference mission, are discussed in the following section.

III. ALLOWABLE AUXILIARY MODULE WEIGHTS

The CSM and Auxiliary Module are, as stated in the Introduction, presumed to be placed in Earth orbit by an SIB launch vehicle. The assumed launch profile consists of a two stage ascent to an 80 x 200 n.m. elliptical orbit, a coast to apogee, and orbital circularization of the CSM/AM/S-IVB spent stage by thrusting with the SPS. The total weight that can thus be placed in a 200 n.m. orbit is taken to be 69,500 lbs.* Allowable weight for the CSM/AM combined is then 69,500 lbs. less the following quantities:**

S-IVB including propellant residuals	26,578 lbs.
Instrument Unit (IU)	4,150 lbs.
Spacecraft LEM Adapter (SLA)	3,800 lbs.

or a net of 34,972 lbs.

The CSM weight is taken to be the Block II dry weight 22,101# (as of May 1, 1966) less the weight of three P&W fuel cell modules removed (660#) and increased by

(a) 9.1 lbs/day average propellant requirement to maintain a minimum orbital altitude of 190 miles***

(b) SPS propellant for orbital circularization and retro (2,883 lbs.)

(c) Asbestos membrane fuel cell weights, the total amount of which vary with average mission electrical power requirements, mission duration, and the expected operating lifetime of the fuel cell modules.

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*Based on SIB capability to place 40,500 lbs. in a 100 n.m. altitude circular Earth Orbit.

**Stage weights used herein are based on Reference 3 unless indicated otherwise.

***Reference 10.

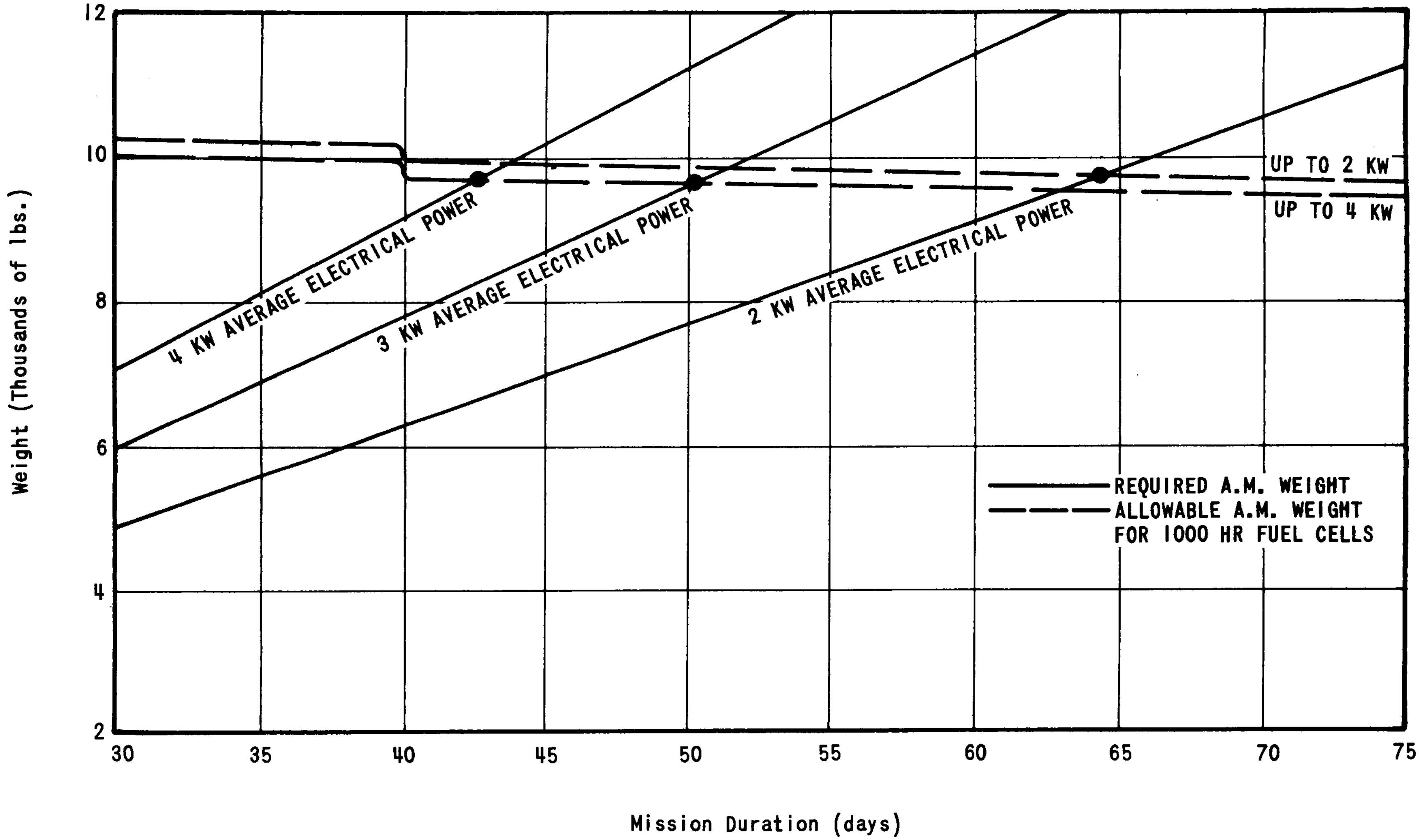

FIGURE 4 - COMPARISON OF ALLOWABLE AND REQUIRED AUXILIARY MODULE WEIGHTS
(S-IB LAUNCH VEHICLE, 200 NM ORBIT, 1000 HOUR FUEL CELLS)

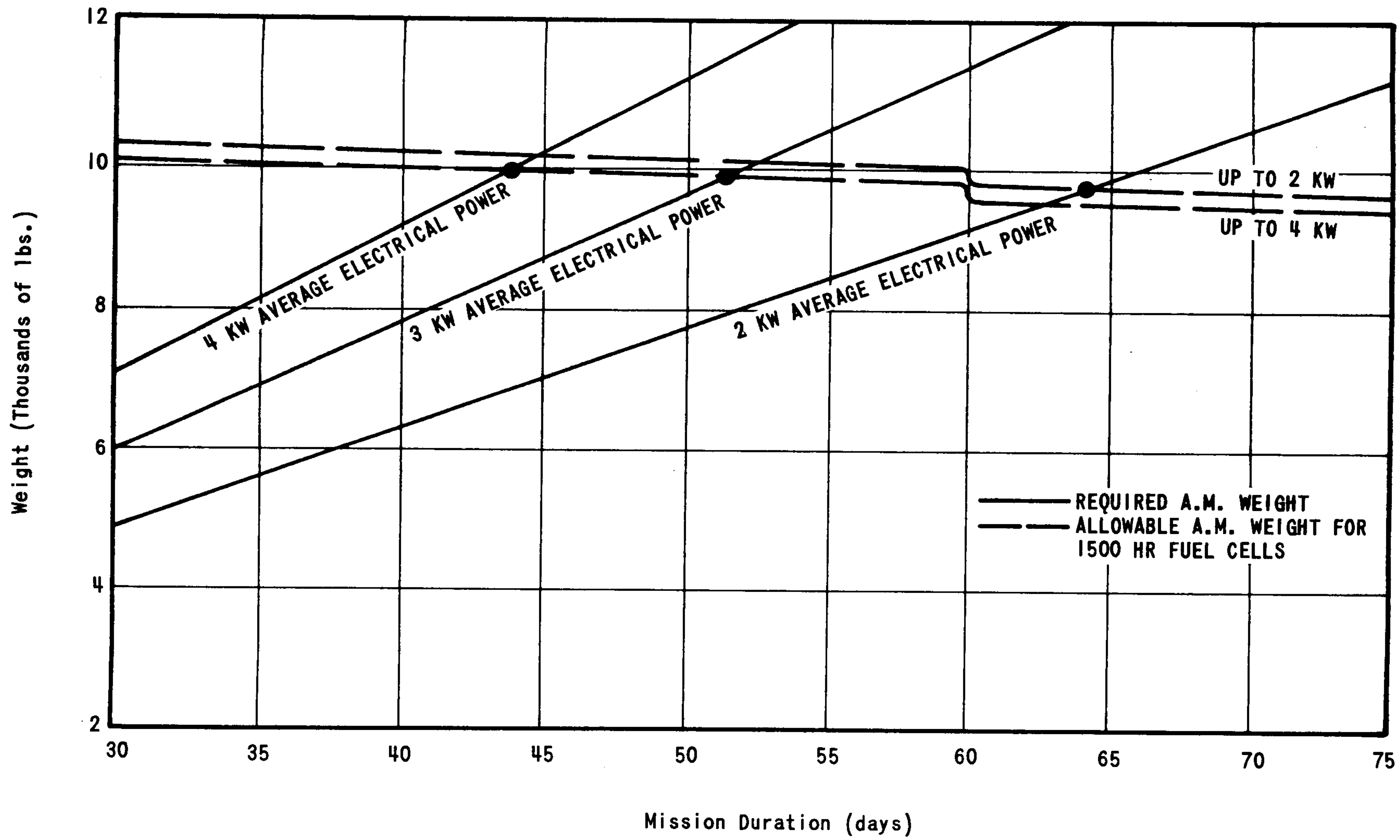

FIGURE 5 - COMPARISON OF ALLOWABLE AND REQUIRED AUXILIARY MODULE WEIGHTS
(S-IB LAUNCH VEHICLE, 200 NM ORBIT, 1500 HOUR FUEL CELLS)

The allowable AM weight is then 34,972# less the CSM weight for a given mission; Auxiliary Module allowable weights are shown in Figures 4 and 5 for mission durations from 30 to 75 days.

IV. RESULTS AND CONCLUSIONS

The preceding sections have defined a preliminary estimate of maximum mission durations obtainable with a minimally modified Block II CSM supplemented by an Auxiliary Module and used to support a pressurized S-IVB Workshop.

The intersections of curves indicating "allowable" and "required" AM weights (Figures 4 and 5) establish a maximum duration on the assumption of no payload allocation to either experiments or systems other than those described previously in Sections I and II.

Maximum durations within that range are 64.4 days, 51.3 days, and 43.8 days for 2, 3, and 4 KW average mission power requirements, respectively. The durations for 3 and 4 KW are sensitive to the assumed operating lifetime of fuel cell modules which is 1500 hours for the figures just cited. Maximum mission durations based on 1000 hour fuel cells with an in-flight start capability are 64.4 days, 50.3 days, and 42.5 days for 2, 3, and 4 KW respectively. The maximum mission duration obtainable (assuming 2 KW average power) is thus 64.4 days regardless of whether 1000 hour or 1500 hour fuel cells are used; the weight and mission-duration advantage of 1500 hour cells over 1000 hour cells for 3 and 4 KW average power levels is thus relatively modest.

Maximum mission durations with various assumed payloads of experiments or augmented systems can also be estimated from Figures 4 and 5. An arbitrarily assumed experiment payload of 1000 lbs., for example, reduces maximum mission durations from 64.4, 50.3, and 42.5 days to 57.8, 45.0, and 39.1 days for 2, 3, and 4 KW respectively (1000 hour fuel cells).

The results of this memorandum provide a means of estimating CSM/AM/S-IVB Workshop mission duration potential for a minimally modified CSM; they therefore provide a preliminary benchmark against which the effects of more extensive modifications can be measured.

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